SPATIUM
No. 45, June 2021, pp. 21-33

UDC 72.013:004.42
72.071.1 Паладио А.
Original scientific paper
DOI: https://doi.org/10.2298/SPAT2145021E

A LANGUAGE-DRIVEN REVERSE-ENGINEERING TOOL FOR THE ANALYSIS OF ARCHITECTURAL PRECEDENTS: A PALLADIAN CASE STUDY

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The analysis of precedents represents a significant point of departure for design processing. By applying a language/ design analogy, this research introduces a reverse-engineering tool that helps guide the systematic analysis of architectural precedents. The visual tool consists of four main layers: the morphological, the semantic, the semiotic, and the pragmatic. To test the tool's applicability, a prominent precedent from the Palladian designs is analyzed as a case study. By developing the tool and demonstrating its applicability for the analysis of the underlying regulatory and formative principles of the Palladian design, this paper aims to contribute to the knowledge of architectural design by introducing an analytical tool for decoding and externalizing the design language. This tool can be added to the existing toolbox of designers, and it can help reveal new insights into the multi-layered compositional language of precedents and their underlying architectonics. The findings related to the tool's applicability and the compositional language of the Palladian design and its associative meanings and connotations are explained, discussed and illustrated by diagrams.

Key words: **Visual Language, Morphogenesis, Geometric Language, Space Syntax, Design Morphology.**

INTRODUCTION

Representing a cornerstone of the pre-design processing stage, precedents are vital sources for extracting retrospective knowledge and developing prospective inspiration. Decoding the designs of precedents in order to deduce their underlying principles, structures, and design methods is a well-established strategy in processing engineering designs. in addressing this strategy, three principal axes collectively form the point of departure of this research.

The first axis is represented by an interdisciplinary incorporation of the reverse-engineering approach into architectural design, in order to generate a tool that can help decode the principles of architectural compositions and their associative designing techniques.

The second axis emphasizes the significance of precedent-based design as a structured design methodology. Emergent designs can be derived based on studying similar precedents and customizing them to fit new requirements and contexts.

The third axis is represented by the view of architectural composition as a visual language. Within the Language-Driven Approach (LDA), devising a Domain-Specific Language (DSL) seems promising in crafting a clear methodology for a designated domain (Mauw *et al*., 2004). Although the generation of DSL is more common in computer applications, this paper follows an LDA to contribute a visual language within the DSL of architectural design. The presented tool, which is referred to as a Visual Design Language (VDL) tool, is rooted in formal techniques, and is structured to demonstrate a holistic system of definite ingredients and a clear process. The VDL is portrayed as four layers of a visual language, with multiple sub-layers within each one. Loaded with meanings and signs, this language represents more than a superficial structure of aesthetic compositions.

This research intertwines the three above-mentioned axes in a reverse-engineering-oriented language-driven tool for the critical compositional reading of architectural precedents.

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The inter-disciplinary amalgamation underlying the tool aims to contribute to knowledge in the areas of precedent-based design, critical analytical studies in the morphology of the built form, the cross-disciplinary incorporation of the reverse-engineering approach in architectural analysis, and the derivative and analytical tools of architectural design management. Notably, the tool is not meant to be restrictive or inclusive. In contrast, it is designed to function as a guide to informing the analysis of building designs and explaining their constituents and aggregation patterns.

The scope of this work lies within the view of language as a syntactic and semantic structure, rather than a human activity (Losonsky, 2006). It is designed to analyze architectural compositions, but it can be extended for other design products in order to explain their implicit structures and methods of production.

RESEARCH DESIGN

Within the scope of architectural morphological analysis, a tool based on an analogy between design and language is presented and discussed here. The VDL tool is developed and devised to function as a reverse-engineering tool that guides the analysis of precedents and, consequently, informs future design synthesis. Thus, the tool has both analytical and synthetic powers. However, the emphasis in this paper is on the analytical aspect to help understand existing building designs. The concept underlying the development of the tool is based on the application of deductive reasoning in order to disassemble a design precedent and analyze its functional components, compositional structures, and design architectonics. This is assumed to be followed by applying inductive reasoning for the synthesis of new forms by combining the components of the various layers to fulfil the new design requirements.

The ontological assumption underlying this research is that knowledge about building design is implicit in its spatial organization and formalistic configurations. The epistemological assumption is that knowledge about precedent design is developed by devising logical and abstract theoretical constructs that are deduced from the dismantling of precedent structures. The reverse-engineering technique represents one of these constructs, applying logical abstraction, as well as deductive reasoning, for design analysis, and abductive and inductive reasoning in the application of the forward-engineering approach for the derivation of similar designs.

The methodological assumption is that architectural compositions convey a formal language, with a structure similar to that of natural languages. Using analogical reasoning, architectural composition can be viewed as a system that consists of a set of vocabulary elements (with semantics and semiotics associations), and syntax grammars that can be context-free or context-sensitive (e.g., Natapov *et al*., 2016). The methodological tools used in the structured analysis of compositional languages in architecture are limited (e.g., Eilouti, 2020a; García-Salgado, 2008). This research is designed to contribute to systematic analysis of architectural products.

It presents a tool that can help in praxis, but which functions more efficiently in educational applications, whereby learners need to understand the multiple dimensions of architectural design.

In addition to the above-mentioned assumptions, this study is based on three major premises. The first is the significance of the investigation of prominent architectural precedents as a reservoir of knowledge. The second is the importance of morphological studies for understanding the stylistic classifications and variations of the built forms. The third is the crucial role of analysis or reverse-engineering for synthesis or forward-engineering in building design. In regards to the first premise, Palladio's works form a significant source of information for understanding the derivation of his designs, the influence of Palladian design on subsequent architectural artifacts, and Renaissance style aesthetics, characteristics, and design principles.

Regarding the second premise, this study is based on a visual analysis of building morphology, namely, a mathematical deductive study of the design component ratios and metrics, and a review of the potential semantic, semiotic and pragmatic forces and influences on the Palladian designs.

The third premise attempts to apply an approach that is successfully implemented in several engineering disciplines in architecture. This reverse-engineering tool can add a new visual tool to the toolbox of designers, which can be used to analyze and synthesize visual compositions in the early phases of their design. This interdisciplinary extrapolation can enhance the precedent-based design methodology in architecture.

In terms of applicability, the compositional analysis method can be a powerful explorative, informative, and intellectual exercise in recycling knowledge and development. It also forms a basis for a comparative analysis between various building designs. Examples of these include a critical study of modern architecture (Frampton and Simone, 2015), a provocative reading of Palladio's plans (Eisenman and Roman, 2015), a formalistic analysis of Palladio's palazzo facades (Eilouti, 2008), and comparative analytical studies of the design schemes of Palladio and Sinan buildings (Eilouti, 2012, 2017). This area of scholarly comparative critical analysis of architectural designs can benefit from the tool introduced in this paper, because of the multiple applications of its structure on various buildings that share a typology or a style, and it can subsequently compare their designs layer-by-layer to reveal their commonalities and differences.

To demonstrate the VDL tool, its testing scope covers the analysis of the morphology and associative meanings, messages, and contextual aspects of the Palladian design. Notably, this paper's primary concern is the visual study of the designated precedent rather than the cultural or social factors – despite their significance – that may have affected its design.

THE THEORETICAL BACKGROUND OF THE VDL TOOL'S DEVELOPMENT

This section includes three components that have been used to develop the precedent analysis tool. These are the precedent-based design, reverse engineering, and the language of architecture.

Precedent-Based Design

This method is based on adapting an existing design to fit a designated similar problem within its context. The customization of an already solved problem, in order to derive new solutions, can save the time and effort of understanding the fundamental elements of the given design problem. Studying the designs of architectural precedents can be significantly informative for practitioners, learners, and educators in the area of systematic design programming and processing (e.g., Clark and Pause, 2012; Eilouti, 2009). Such a study can help designers externalize the implicit design principles and the style derivation tectonics, which are typically ambiguous in architectural presentations. In education, a critical analysis of buildings that share a typology or a style with the problem at hand represents an intellectual exercise and an evaluative and formative pedagogical experience for learners and educators. Applying a deductive reasoning approach helps to conclude the rules of composition, derivation methods and morphosis techniques out of pictorial representations. In practice, an explicit system of designing may provide a clear point of departure for generating designs and assigning the styles of spatial organizations. Examples of translating the deductive analysis of designs into an inductive form of generating methods include precedent-based instruction studies (Akin, 2002) and the example-based design processing method (Sio and Kotovsky, 2015).

This research applies a morphology-oriented model to decoding precedent designs. Many scholarly works are concerned with the morphological analysis of the built form in architectural literature. Examples of these include a critical analysis of modern architecture (Frampton and Simone, 2015), a provocative study of Palladio's plans (Eisenman and Roman, 2015), and a comparative analysis of the design schemes of Palladio and Sinan in their sacred buildings (Eilouti, 2017). In addition, there are related studies about precedent-based design paradigms, such as developing new approaches that recycle knowledge from precedent-based solutions to problems (Agarwal and Poovaiah, 2015; Eilouti, 2009).

Reverse Engineering

Reverse-engineering is a top-down case-based approach to design. It is the process of extracting knowledge from an existing human-made product and reproducing a new product similar to the original or inspired by it, based on the extracted knowledge (Eilam, 2005). Resulting knowledge from the reverse-engineering processes can be applied in a subsequent bottom-up forward-engineering approach to the design of similar products. Hence, reverse engineering functions as a systematic analytical tool and a technique of problem-solving that informs a subsequent synthesis of design products. It has applications in many fields, such as bio-medicine, chemistry, mechanical and civil engineering, computer programming and manufacturing, as well as industrial applications (e.g., Ali *et al*., 2014; Chikofsky and Cross, 1990; Varady *et al*., 1997; Warden, 1992). Although indirectly implemented in case analysis, its applications in architecture are still under-represented.

The Language of Architecture

Allegorically, formal languages and natural languages converge in multiple aspects of their structures. The notion of architectural composition as a visual language is not new and is still debatable (e.g., Salingaros, 2006; Summerson, 1966). Throughout history, the application of the visual language lens to viewing architectural design has evolved through multiple versions, with each emphasizing various combinations of the syntax, morphology, signs, behavior patterns, and/or symbolic layers of its configuration. Several of these transcend the typical prosaic dimensions to include high-order poetic and trope-loaded dimensions (Simitch and Warke, 2014). Most of these versions agree that architectural form communicates meanings such as welcoming, defensiveness, protection, uplifting, hierarchy, sacredness, connection, order, chaos, and flow. They also agree that buildings have a purpose beyond pragmatic sheltering and functioning as machines for living or working. In most versions, architectural form is viewed as a complex order of language that merges high levels of abstraction with pragmatic levels of materialization. The primary substances of its expression include shapes, forms, spaces, masses, surfaces, colors, textures, and construction materials.

The language of architecture can be positioned at the intersection of visual languages (e.g., Bermúdez, 2003; Breen, 2019; Kiroff, 2002), natural languages, and the composition of designs (Norberg-Schulz, 2000; Remizova, 2016; Simitch and Warke, 2014, Tayyebi and Demir, 2019). In the area where visual and verbal languages intersect, the generation of complex structures out of primitive elements and syntactic rules is described by Chomsky's generative grammars (Chomsky, 1965; Gandelzonas, 1983). Peter Eisenman introduced a series of residential designs that he called 'cardboard architecture', in which he embodied what he referred to as 'deep structure' to explore the concept of 'visual syntax'. The premise of this approach stemmed from Eisenman's interest in language structure and semiotics. In Eisenman's architecture, the design process is synchronized with the process of researching formal structures and fractal geometric shapes (Eisenman, 1983; Gandelzonas, 1983). Similarly, Eisenman and Roman (2015) graphically analyzed 20 Palladian villas and illustrated the evolution of emergent villas similar to the classical precedents. Moreover, Simitch and Warke (2014) proposed a language of architecture that provides a system that conveys meanings. However, this language's traits are comparable to a "thick" poetic language (Simitch and Warke, 2014).

Notably, this research is aware of the developments in the fields of linguistics and biolinguistics. However, these extended horizons are out of the scope of this study. Furthermore, the exact syntactic rules of generating form, as addressed by generative shape grammars (e.g., Eilouti, 2019), are also out of this paper's scope.

A REVERSE-ENGINEERING VDL TOOL FOR DECODING THE DESIGN OF ARCHITECTURAL PRECEDENTS

While the formulation of a language system helps codify a large number of visual compositions in succinct structures, a system that dismantles these compositions can help to decodify them in order to understand their lexical and tectonic principles. To help decipher the compositional structure underlying a given building design, this section introduces a tool that helps in the analytic phase of processing architectural design. Structured tools for design analysis are still limited. The tool developed in this section aims to contribute a figurative and operative addition to a designer's toolbox. The tool aims to help decrypt the design configurations of architectural precedents and guide the analysis and comparison of various designs. Moreover, the tool can be applied to guiding the synthesis of future similar products. However, this forward-engineering application is out of the scope of this research.

The tool consists of five concentric circles that move from the general levels outwards into the more specific sub-levels (Figure 1). The circular structure is divided into four major geometric sectors. Based on a composition/language analogy (e.g., Bauer 2003; Harrison 1978), these sectors represent the morphological, sematic, semiotic, and pragmatic layers of a design language. The first sector is concerned with the form and appearance of a given building. Its structure consists of four segments, each of which highlights one aspect of the compositional language of architectural products. It consists of morpho-lexical, morpho-syntactic, morpho-metric, and morpho-graphic layers. While the first emphasizes the geometric and spatial vocabulary elements of a compositional language, the second is mainly concerned with the rules and methods of assembling vocabulary. The third is concerned with the measurements and proportional systems underlying the aggregation of form. The fourth is mainly concerned with the graphic representation of some of the systems used in the second and third layers.

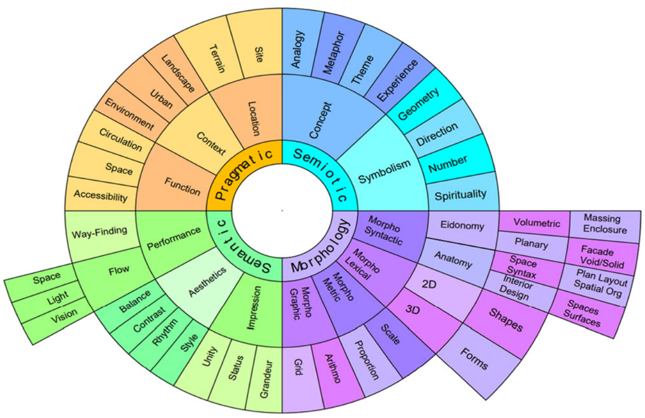


Figure 1. The language-based reverse engineering VDL analytic tool

The second sector of the circular model transcends the boundaries of formalistic manifestation in an attempt to explore the meanings underlying the superficial appearance of buildings. The semantic layer explores the meanings associated with aesthetics, performance and impacts of compositions on users and viewers.

The focus of the third sector is on the messages and signs sent directly or indirectly by architectural compositions. It is concerned with the concept behind a design and the symbolic connotations it is loaded with.

While the previous three sectors deal with the built form as a context-free product, the fourth emphasizes the form as a context-sensitive entity. The pragmatic segment investigates the location influences, the context-related aspects and the functional considerations of a design. Following is a further-detailed discussion of these four sectors.

The Morphological Layer

As illustrated in Figure 1, the VDL tool consists of four layers. The first emphasizes the form-related aspects of architectural compositions, with a focus on the visual composition and both its ingredients and aggregation configurations (e.g., Niezabitowski, 2018). The morphological layer, in turn, comprises four major sets of classes. These are:

- **The morpho-lexical class**. It consists of the fundamental vocabulary elements of a compositional language, including two-dimensional shapes, planes and surfaces, and three-dimensional forms, masses and spaces.
- **The morpho-syntactic class**. It focuses on how the primary vocabulary components are synthesized. It can be classified, in turn, into two subcategories of attributes related to form, that is, the eidonomy and the layout anatomy. The former is concerned with the external characteristics, whereas the latter focuses on the internal relationships of the vocabulary-related components, such as their proximity and enclosure attributes. This class highlights features such as the topology, regulatory lines, organizational devices such as infrastructure, datums and grids (Simitch and Warke, 2014), zone clustering, spatial organization schemes, compartmentalization, layering and symmetry.
- **The morpho-metric class**. It consists of the numerical assignment to the parametric schematic planning schemes of a given design. It includes proportional systems, measurements, and the dominant scales. While the previous classes are concerned with the qualitative attributes of design, this class applies basic mathematics to interpret the quantitative aspects.
- **The morpho-graphic representation**. This set translates the mathematical relationships between space lexicons and the topological proximity relations of space syntax into an arithmo-geometric graphic representation. It also includes graphic representations such as the Nine-Square Grid (9SG), Pythagoras tree and the fractal chart of recurrent ratios. The 9SG is an abstract diagrammatic tool that is used in architectural planning and design to organize major zones and determine their topological relationships. It takes the form of a three-column by three-row matrix. It typically dictates topology and assigns order to the various elements it regulates. Eisenman (1999) proposes that the diagram's pedigree developed in the form of the nine-square problem as an antidote to the bubble diagramming of Bauhaus functionalism. In terms of its functionality, the 9SG can be viewed as an operative, derivative, figurative, and representative tool. In the first sense, it functions as an organizational tool that relates elements of design in space. In the second, it functions as a generative tool that helps derive new designs by

proposing a layout configuration. In the third sense, it dictates the rudimentary shape of the final composition. In the fourth, the 9SG functions as a pictorial abstraction of spatial organizations, where squares represent spaces and lines represent walls or space limits. Every line in this representation suggests a delimitation or demarcation of space that can be translated into separation, union, subtraction, or addition of masses. In terms of its semantics, the 9SG represents forces, themes, scenarios and historical connotations. Addressing the semantics of 9SG, Somol (1998) proposes that the beauty of the 9SG lies in its abstraction and immateriality, whereby it transcends function, site, client, body, and scale. The architectural literature is rich with research about the 9SG (e.g., Eisenman, 1999; Hedjuk, 1985; Kalfazade, 2009; Wittkower, 1971). Furthermore, some examples compare architectural precedents using the 9SG. For example, in the essay Mathematics of the Ideal Villa, Rowe (1977) compares Andrea Palladio's Villa Malcontenta and Le Corbusier's Villa á Garches using abstract diagrams that are analogous to the 9SG layout. Similarly, Rudolf Wittkower in his book Architectural Principles in the Age of Humanism (1971) analyzes Palladio's villa designs and their geometric languages in the context of 9SG. As a result of this analysis, Wittkower concludes that the geometrical pattern of the Palladian villas is the 9SG (Wittkower, 1971).

The Semantic Layer

The second sector in the VDL tool emphasizes the semantic implications of a design in terms of the meanings assigned to its vocabulary elements, as well as those associated with its space syntax. Hence, the main concern of this layer is the set of connotations that includes, but is not limited to, meanings that can be categorized into three classes:

Aesthetics-related meanings

- ***Balance***, which is mostly expressed by symmetry in classical designs. This is also related to another aesthetic value, that is, order. In product design, order can be achieved by a regulatory grid, shape repetition and datum line.
- ***Contrast***, which can take the form of a juxtaposition of void and solid, addition and subtraction, and/or the combination of simplicity and complexity in a given composition.
- ***Rhythm***, which is associated with the harmony of recurrent elements. Rhythm can be constant, alternate, ascending or descending. Depending on which rhythm is adopted in a composition, a meaning related to monotony, variety, growth or decline is conveyed.
- ***Style*** of a composition can express a statement about a design's formalistic membership or temporal/ geographic reference.

Impression-related meanings

- ***Unity*** vs. fragmentation. A composition may provoke a feeling of consistency and unity or, otherwise, a feeling of duality, multiplicity, chaos or fragmentation.
- The ***monumental*** scale exaggerates some elements or dimensions, in order to convey the importance or grandeur of particular components.
- The social or cultural ***status*** of a building's owner may be conveyed by means of the design syntax.

Performance-related meanings

When a group of spaces is clustered, its configuration helps impact its users and viewers with experiences such as:

- ***Flow*** of vocabulary elements. This includes flow of the spatial organization, of light or sound throughout the building, and of visual continuity among spaces.
- **Way-finding** to, around and inside a building. This is related to ease of accessibility, smooth circulation, and use of reference points that are easy to distinguish and remember while moving in a building.

The Semiotic Layer

This sector expresses the messages and signs sent by a building to its viewers. It can be considered similar to a human body language. It addresses the symbolic and conceptual aspects of a design. *Symbolism* may employ the geometry, directionality, occurrence and spirituality of spaces. For example, a dome is a geometric solid that is associated with temples and can be employed to signify the universe or heaven, and to convey a message about the sacredness of the building at hand. Similarly, the *verticality* of a dominant object in a composition may signify connectivity between earth and sky. Furthermore, repeating components with a particular *number* may represent a specific reference, person or era. Similarly, the employment of a *flow* of natural light and a visual connectivity may symbolize *spirituality*. In addition, the semiotics of a design may be represented by a concept or a designer's philosophy, which may be conveyed by the articulation and configuration of a form (Eilouti, 2018a, 2018b).

The Pragmatic Layer

This sector represents the pragmatic layer, which addresses the contextual fitting of a design within its direct and indirect environments. This layer includes the site considerations, as well as the urban and environmental contexts of a building. The pragmatic layer also includes the functional considerations of a design. Function assigns a meaning and a purpose to space clusters, which helps to transform them from artistic sculptures into usable and livable structures. Such a dimension is related to how the end users of a building are expected to behave when using it. It includes attributes that make a space usable and issues related to its accessibility, circulation and place-making (Eilouti, 2020).

THE CASE STUDY

The architectural library is rich with publications related to Palladio's designs and his influence on architecture throughout the ages. Examples of these include Rowe's book on the proportional system and numerical aspects of Palladio's villa designs (Rowe, 1977), Wittkower's study of the principles of Palladio's architecture (Wittkower, 1971), Eisenman and Roman's research on Palladio's works (2015), Hersey and Freeman's possible Palladian villas (1992), Stiny and Mitchell's study of The Palladian Grammar (1978), Beltramini's studies of Palladio's works (2009), and Mitrovic's (2004) analysis of Palladio's designs. Despite the copiousness of the studies about Palladio designs (e.g., Ackerman, 1967; Constant, 1993; Murray, 1971), the area of structured analysis that systematically examines the multi-dimensionality of his design language is still under-represented.

One of Palladio's most influential works was selected to represent his designs. Following is a discussion of its structure.

San Giorgio Maggiore

Skillfully articulated with characteristics of Renaissance architecture, the church of San Giorgio Maggiore was designed by Palladio and built in 1566 on an island of the same name in Venice, Italy. The concept underlying its design is based on an analogy with the Temple of Augustus. Interestingly, this concept applies a precedent-based design methodology. The main façade facing the water lagoon represents a superimposition of two Roman façades. The larger is recessed and consists of a wide pediment, and an architrave that is clearly supported by pilasters and extends over the nave and two lateral aisles. The smaller façade is projected and consists of a narrower and higher pediment that extends over the nave and is superimposed on top of the previous façade, with a giant order of four engaged columns that are raised on high pedestals. On either side of the central portal are statues of the religious figures to whom the church was dedicated. The portico includes massive engaged columns and pilasters on plain external white-surfaced walls. The internal layout combines a long Basilican nave with a cruciform plan that complements the nave with transepts. The interior of the church is bathed in light from the windows and clerestory openings. This effect is enhanced by the majestic Diocletian windows that channels natural light into the portico, arches and apses. The interior is decorated with paintings that are placed on either side of the presbytery, where they can be seen from the altar rail. A key measurement unit of the façade of the San Giorgio Maggiore church is the diameter of the large column at its base. It is the key element of the proportional system applied to this design. For example, the ratio of the diameter of the major order columns to their height is 1:15, which is the proper proportion for a Corinthian column as laid out in the MIT Press English edition of Palladio's Four Books of Architecture (1997). In addition, the distance between the columns surrounding the portico is twice the diameter measurement.

THE VDL of San Giorgio Maggiore

The VDL tool introduced and described in the previous sections will be applied on the church of San Giorgio Maggiore in this section to decode the various layers of its compositional language.

The morphological analysis

This section is concerned with the shapes, spaces and forms of the church in their individual and aggregational representations on the internal and external levels. It presents a reification of the four sub-layers of the lexical, syntactic, metric and graphic interpretations of the pictorial analytic tool (Table 1).

<u>The morpho-lexical analysis</u>

In reference to the ground floor plan of the San Giorgio Maggiore church, the main 2D lexemes are squares, rectangles, circles, and semi-circles. The lexical components are repeated with various scales and proportions. Regarding the treatment of the main façade, the basic vocabulary elements consist of rectangles, circles, sectors, semicircles and triangles. The three-dimensional blocks include the parallelepiped, cube, cylinder, cone, pyramid and hemisphere masses (Table 1). In addition, extruded meshes and nonuniform solids in the art statues are used as a supplementary ornamentation to the main masses.

<u>The morpho-syntactic analysis</u>

In terms of the syntax of San Giorgio Maggiore church, the formal lexemes were subject to multiple transformational operations. These include scaling, stretching, mirroring along orthogonal axes, transmission, and rotation.

Adjacency of blocks is the main topological relationship. There are no intersections or overlaps between the plan units. The main clustering and enclosure techniques are based on the mirroring of masses around a major axis in a linear scheme. The dominant modelling technique is the extrusion of planes, rotation of cross-sections in the domes and columns, and application of an additive approach for mass clustering. The latter can be seen in the porticos and the semi-cylindrical masses surrounding the main nave mass. The articulation of the plan suggests that the spatial planning technique underlying its structure is based on a clear manipulation of an orthogonal grid, and an apparent implementation of a parametric 9SG scheme. The highly abstracted schematic representation of the church floor plan reflects a structure that combines at least two sets of superimposed 9SG layouts. The first is used in the peripheral eight-corner squared spaces surrounding the introductory nave. The second is applied to the domed space and its surrounding four squares and four rectangles. The latter 9SG overlaps with the previous one and is applied to emphasize the major grid-driven regulatory scheme in the composition (Figure 2). In the main façade treatment, Palladio's solution to the problem of the differences in heights of the central nave and the side aisles of the church was based on incorporating the actual pitch of the two roofs rather than merely concealing any of them. He skillfully integrated the two pediments that cover the two pitched roofs aesthetically and structurally. The main façade combines two types of columns: engaged columns and pilasters. Although the same two column forms are used both inside and outside the church, they are configured differently. Externally, on the main façade, the colossal components are all engaged columns, whereas the colossal elements in the interior are both engaged columns and pilasters. The orders of the exterior, as well as the interior, columns of San Giorgio Maggiore are used in two sizes and types. These are the Composite order in the large columns and the Corinthian order in the small ones. Externally and internally, ornamentation is not used in the surface treatment, with the exception of detailing the column capitals.

The church's composition displays duality between the language used in the front façade manipulation and that used in the other façades.

<u>The morpho-metric analysis</u>

A ratio of 1:1 is used in the central circle and the main squares

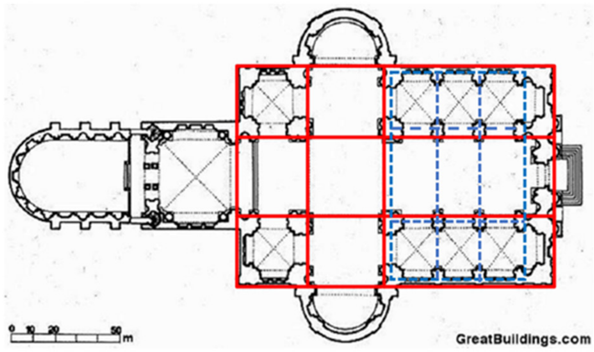


Figure 2. Nine-square grid abstraction of the San Giorgio Maggiore planning scheme

in the side aisles of the church. This ratio is also used to relate the main nave and transepts. As illustrated in Figure 3, the main proportional ratios used in relating the elements of this plan are: 1:1 in the squares and circles, 1:2 in the semi-circles and in the introductory nave, 3:5 in the back space and 1:3 in the repeated three lateral cells. The proportion of 1: √3 is used in the largest rectangle containing the nave and aisles (shown in dashed green lines). In addition, the dual scale of the orders is used in the main façade. In using a dual-scale for the orders, Palladio followed Alberti's guidelines for the configuration of the colossal columns (e.g., Santa Maria Novella and Sant' Andrea).

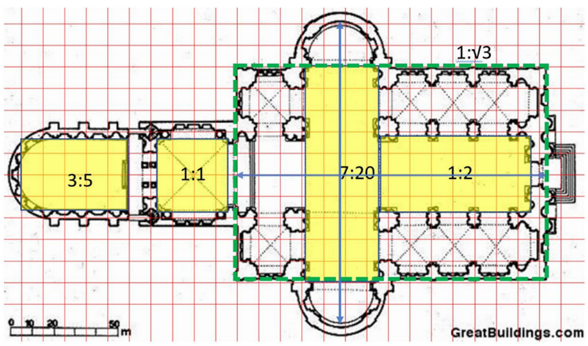


Figure 3. The proportional system of the San Giorgio Maggiore church

The morpho-graphic analysis

The proportional system applied to the ground floor plan is illustrated by an arithmo-geometric representation that uses basic regular equilateral convex polygons to illustrate the major proportions, which are repeated in the plan (Table 1). The set of polygons that represents the proportional system of the church comprises regular tetragons and hexagons. The rudimentary unit in this representation is a square with a one-unit measurement for each side. With a hexagon constructed on one of the edges of the basic square, the length of its shorter diagonal demonstrates another ratio, that is 1: √3. This ratio is used in the rectangle enclosing the central nave and aisle space. The length of the longer diagonal demonstrates a ratio of 1:2, which relates the lengths of the semi-circular shapes to their radii. The diagonal length of √3 is used to construct another hexagon. The shorter diagonal chord of this latter hexagon represents another ratio that is applied in the side aisles of the church.

The semantic interpretation

The meanings that may be concluded from the internal and external spatial structures of the church include:

- The ***monumental*** *scale* that expresses significance and grandeur. It is represented in the central axial nave spaces, main dome, and elevated portico. It is also apparent in the platform above which the whole church is raised.
- ***Balance***: The spaces are symmetrically arranged along the main axis to represent order, control, stability, balance and power.
- ***Contrast***: This is demonstrated by the juxtaposition of the verticality and horizontality, void and solid forms, addition and subtraction, simplicity and complexity, and rectilinear and curvilinear geometric articulations, which are all balanced and contrasted in the overall design scheme. Furthermore, the contrast components of soft and sharp geometry, and sea and land contexts imply the duality of the worlds of sacred and secular, and this life and the afterlife.
- ***Order***: The vocabulary elements of the church design are organized together in a highly-ordered configuration. This is demonstrated by the application of the regulatory 9SG, and by the ascending rhythm when moving from the main entrance towards the rear altar and choir halls.

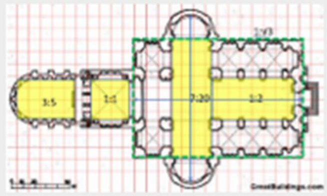
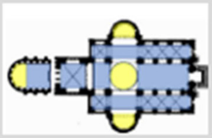
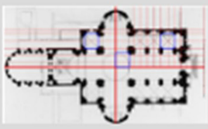
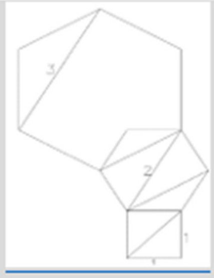
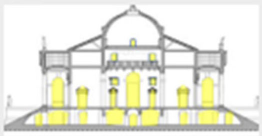
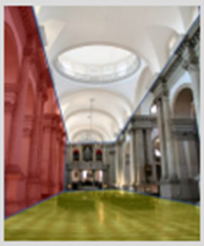
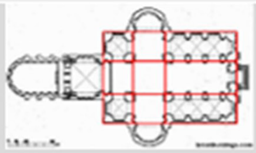
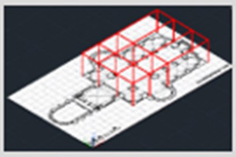
The semantic elements are illustrated in Table 2, where it can be seen that some design features contribute to both semantics and semiotics, such as order, balance and fluent light and movement. The distribution of natural light is echoed by the acoustic distribution. To solve the visual and acoustic flow throughout the spaces, San Giorgio Maggiore has several features that enhance the worshippers' ability to see and hear the services from the nave.

These include the placement of the monks' choir behind the altar to assure the laity the unobstructed view and sound of the high altar, the use of a screen of columns and arches to form a background to the altar, the elevation of the altar to increase its visibility from the entrance, and the placement of a barrel vault over the nave to make the prayer more audible. In addition, to further emphasize the flow of the light effect and to provide optimum natural lighting for viewing processions and rites, a set of clerestory thermal windows was placed in the bases of the barrel vaults over the nave and transept arms.

The pragmatic factors

The church's seaside location signifies its prominence as an iconic landmark that attracts the attention of viewers from other islands. The composition's reflection on water adds to the majestic character of the church and duplicates its effect. The balanced combination of verticality and horizontality simulates the calm nature of the surrounding water body (Table 3). Pragmatic analysis reveals a non-harmonious response to the site and context, as well as a lack of connectivity between the building and its surrounding

Table 1. The morphological analysis of San Giorgio Maggiore

Layer	Aspect	Application	Layer	Aspect	Application	Layer	Aspect	Application
Morpholexical	Two-Dimensional		Morphosyntactic- Eidonomy	Massing		Morphometric	Scale	
	Three-Dimensional			Enclosure			Proportion	
Morphosyntactic- Anatomy	Space syntax	 		Facade		Morphographic	Arithmo-graphic	
	Spatial Organization			Openings				The ratio of the diameter of the major order columns to their height is 1:15, which is the proper proportion for a Corinthian column (the Corinthian order is the slenderest). Column ratio 1-1/6
	Interior Design			Surface Treatment			9 Square Grid	 

environment. In terms of function, the method of clustering the main spaces together achieves the main purpose of the building, that is, hosting mass prayers and facilitating way-finding, accessibility, circulation and comfortable praying. The church is easily accessible with clear way-finding routes. The most intensive movement areas are centered around the major axis of symmetry, as it directly connects the indoor and outdoor spaces. From the main entrance, it is possible to see the whole altar space. All spaces are visually and topologically well-connected and well-lit.

The semiotic aspects of the church

Externally, the main messages sent by the massive articulation of the church are related to the accentuation of its sacred identity. These messages are further emphasized by the massive central dome, and the majestic front facade. Internally, the exaggerated heights of the central nave, the divine flow of natural light, and the employment of a dome that symbolizes heaven are all employed to emphasize the spirituality of the building. In addition, the verticality of

Table 2. The semantic features of San Giorgio Maggiore

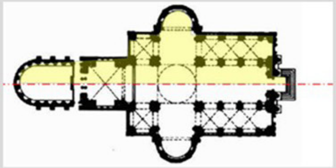
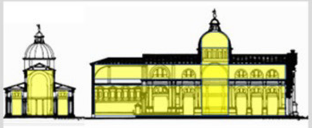
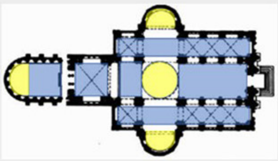
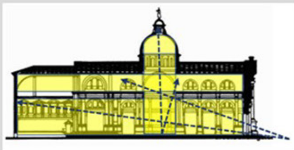
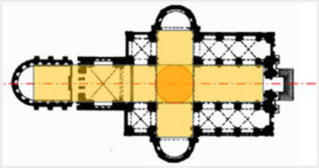
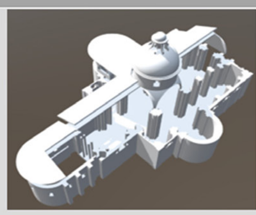
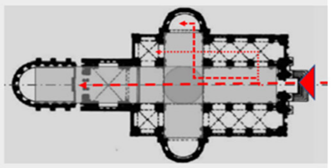
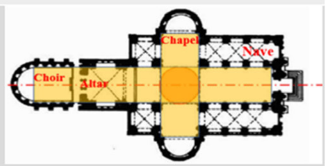
Layer	Aspect	Application	Layer	Aspect	Application	Layer	Aspect	Application
Aesthetic	Balance		Performance	Spatial Flow		Impression	Unity	
	Contrast			Light Flow			Monumentality	
	Rhythm			Visual Flow			Status	
	Style			Way-Finding			Soaring	

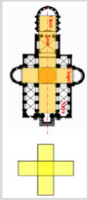
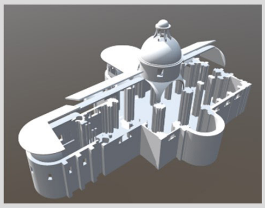
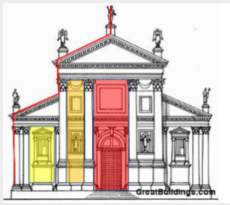
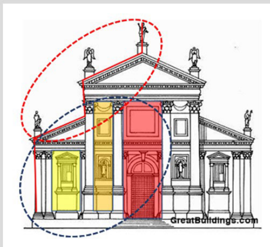
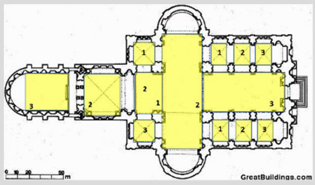
Table 3. Pragmatic features of San Giorgio Maggiore

Layer	Aspect	Application	Layer	Aspect	Application
Location	Site Plan		Function	Spaces	
	Landscape			Accessibility	
Context	Environment			Circulation	

the bell tower symbolizes connectivity between earth and sky and highlights the divine character of the building. The dominant character of the spaces is introvertive, as it channels the users' attraction into the altar space. The major semiotic features of the church are illustrated in Table 4.

The four layers of the tool have been applied to the church to reveal various aspects of its design structure. The isolation of each layer to understand its associative properties and design features helps organize the analysis process and reveal new attributes of the design structure. Moreover,

Table 4. Semiotic features of San Giorgio Maggiore

Layer	Aspect	Application
Symbolism	Geometry	   https://sketchfab.com/3d-models/san-giorgio-maggiore-3a980b23c4f54ab6a48168418025e72e
	Directionality	 
	Number	 
	Spirituality	  https://www.akg-images.com/archive/-2UMEBMY20AVN0.html
Concept	Analogy Pantheon, Rome, Italy	 http://www.greatbuildings.com/cgi-bin/gbi.cgi/Pantheon.html/cid_1349932.jpg

the structuredness of the pictorial VDL tool facilitates the systematic visual reading of the precedent and helps guide the process of its incremental analysis. Inferences from the analysis can help synthesize other designs and emphasize new features to add deeper meanings to their manifestation. This derivative dimension of the tool can be addressed and discussed in a future extension of this research.

CONCLUSION

Architectural precedents represent a rich reservoir of knowledge. The structured analysis of precedents is an intellectual exercise, a technique for forming knowledge, and a major component of the pre-design programming of architectural design. It also forms a basis for precedent-based design methodology. To help decipher the compositional language underlying precedent designs, a systematic pictorial VDL tool is presented. The tool is based on an analogy between architectural compositions and natural languages. It is designed to guide the reverse engineering process of decomposing the design of a precedent in order to isolate each layer and reveal its constituents and their relations and impacts on the resultant configuration. The tool consists of four major layers that are associated with multiple, more specific, sub-levels. The primary layers represent the morphological, sematic, semiotic, and pragmatic layers of the design language.

The analytical reverse-engineering VDL tool, as developed and applied in this paper, seems to facilitate the structured analysis of architectural precedents and highlight some of the implicit features.

To demonstrate the applicability of the VDL tool, a prominent Palladian precedent is selected. The San Giorgio Maggiore church, which represents the religious typology, is selected as a case study of the tool because of its rich syntactic and semantic composition. Applying the tool, the Palladian precedent is critically analyzed to conclude the principles underlying its compositional structure in terms of its morpholexical, morphosyntactic, morphometric, morphographic, semantic, semiotic and pragmatic configurations.

On the morpholexical level, the basic elements of the geometric vocabulary include the rudimentary two-dimensional shapes of squares, rectangles, circles, semi-circles and triangles, and the basic three-dimensional volumes of parallelepiped, cones, cylinders, pyramids and hemispheres.

On the morphosyntactic level, multiple transformational operations such as scaling, transition, rotation, and mirroring were used. Within this level, a parametric version of the 9SG can be found in the regulatory scheme of the plan. However, this resemblance between the nine-square grid and the precedent's layout does not necessarily suggest that Palladio applied this tool in his planning scheme.

On the morphometric level, the proportions of 1:1, 1:2, 3:5, 7:20 and 1: √3 were repeated to order the numeric relationships between the design elements. These ratios exhibit proportions that are close to the golden section.

On the arithmo-geometric level, the proportional system is represented as regular polygons and as a parametric 9SG. In this regard, the morphographic representation in the church applies a regular tetragon and hexagon as a proportion representation.

The semantic layer was expressed in the dramatic application of monumentality, verticality, directionality and ascending rhythm in the church. The monumental scale, balance of masses, contrast of features, order of configuration and flow of spatial organization all manifest the building's significance and status. The church's composition displays duality between the language used in the front façade manipulation and that used in the other façades.

The pragmatic analysis reveals a non-harmonious response to the site and context, as well as a lack of connectivity between the building and its surrounding environment. However, harmony between the building and its site appears stronger in the main façade of the church, which amplifies the interface between the sea and land in its design to attract viewers from a distance away. Despite the emphasis of the land-sea interface, the formal appearance of the façade still contrasts with the spontaneous character of the sea. In terms of function, the way spaces fulfil their expected purpose is apparent in the church. The semiotic aspects highlight the messages sent by the design about its concepts, symbolism of the masses, and expression of power and control. In addition, the verticality of the tower and nave sends messages about the connectivity of earth and sky through praying. The divine character and expression of spirituality exist in the spatial and visual flow of the design. In addition, the employment of a number of building blocks is clear in the design. The duplication of elements is dominant in the church because of its perfect symmetry, and the number three is repeated as a result of religious references.

The VDL tool seems to successfully function as effective guidance for the systematic analysis of architectural precedents, and as a reminder to explore new dimensions in the design process. However, the tool requires more applications to discover its limitations and develop its structure to explain more recent typologies and styles.

The VDL tool has potential as a synthetic tool that helps re-assemble the knowledge extracted from the analysis to produce emergent designs using a precedent-based design/forward-engineering methods. However, derivative power was not addressed in this paper. Development of this power represents a future extension of the research.

Another extension is to compare the secular and sacred designs of Palladio, in order to conclude their design structures and discover their commonalities and differences, and externalize the detailed generative rules of their compositions and architectonics. In terms of the methodological aspects and mechanisms, the analytical tool can be developed to cover more layers of design language, such as the addition of the phonetic layer and its counterpart of kinetics in architecture.

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Received August 2020; accepted in revised form March 2021.